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<p>14. ABSTRACT</p> <p>One of the major hurdles facing CFD practitioners is simplifying highly detailed models that were constructed for manufacturing. Features that are below the length scale of interest to a simulation, such as CFD, must be removed prior to meshing. Importing neutral files such as IGES can be particularly time consuming because sometimes you get many disconnected sheets.</p> <p>Goals</p> <p>The overall objective of this effort is to reduce the time required to prepare models for CFD from in some cases weeks to under a day. The reduction in model preparation time comes from the new ability to automatically remove features from a model and assist the analyst in resolving geometry import problems.</p>					
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Automated Preparation of Geometry for Computational Applications Final Report

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December 14, 2010

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2. PROJECT INFORMATION

2.1. Administrative Information

2.1.1. Subcontractors

No subcontractors were used in this effort.

2.1.2. Performing Organization Contacts

2.1.2.1. Principal Investigator Contact

Dr. Alan Magnuson

CADNexus, Inc.

101 Cambridge St.

Suite 370

Burlington, MA 01803

Tel: 781-229-0200

Fax: 928-396-1689

Email: magnuson@cadnexus.com

2.1.2.2. Contract/Administrative Contact

Petra Botha

CADNexus, Inc.

101 Cambridge St.

Suite 370

Burlington, MA 01803

Tel: 781-229-0200

Fax: 928-396-1689

Email: pbotha@cadnexus.com

2.1.3. Application User

Not applicable.

2.2. Programmatic Information

2.2.1. Project Uniform Resource Locator (URL)

The project URL is <http://www.cadnexus.com/projects/A093-132-1055/>

2.2.2. Project Description

2.2.2.1. Research Objectives

Objective 1: Import of production level CAD files

Objective 2: Identification and repair of geometry not imported correctly

Objective 3: Identification of features and automatic removal of internal / external selected features

Objective 4: Automatic generation of a unified watertight mesh over one or more components which closes gaps and holes not selected for retention

Objective 5: Export resulting geometry and/or mesh to most formats commonly used in grid generation tools

2.2.2.2. Problem Description

One of the major hurdles facing CFD practitioners is simplifying highly detailed models that were constructed for manufacturing. Features that are below the length scale of interest to a simulation, such as CFD, must be removed prior to meshing. Importing neutral files such as IGES can be particularly time consuming because sometimes you get many disconnected sheets.

Research Goals

The overall objective of this effort is to reduce the time required to prepare models for CFD from in some cases weeks to under a day. The reduction in model preparation time comes from the new ability to automatically remove features from a model and assist the analyst in resolving geometry import problems.

Expected Impact

The expected impact of streamlining geometry preparation is that candidate designs can be identified much more quickly resulting in drastically reduced design cycle time. In the government sector this translates to ability to more quickly field better more

efficient hardware. In the commercial sector this translates to faster time-to-market thereby increasing the competitiveness of companies using the GPW.

The specific market need the CADNexus sees is relief of the pain of manually doing pre-processing on geometry prior to doing performing analysis on models. Analysts spend a tremendous amount of time and effort on manual healing and repair. It can take weeks to get a sophisticated model prepared for analysis. CAPRI users have in some cases reduced this time down to a few hours. This is time that can be better spent doing engineering and improving the target product. The pain is wide spread throughout the aerospace and auto industries and generally in product design where analysis is utilized.

Model Clean-up is a pervasive problem throughout the product design industry. Analysts consider it a critical or at least important issue in over 50% of product development organizations¹. In a recently published study on "Model Clean Up" the authors found that 34% of analysts interviewed said that over half of the analysis tasks they performed required model clean up. The study also found that 50% of respondents must remove details from their models for 50% of the tasks they perform. While fixing topological errors seems to be accepted by the community as inevitability there seems to be pent up demands for tools that help analysts de-feature models.

2.2.2.3. Technical Approach

Detailed Description of Technical Approach

Phase 1 includes import of STEP files, performance improvement of various CAD preparation steps, and export of the geometry or mesh representation to various meshing formats and packages. The components of the Phase 1 approach that address these requirements are enumerated below.

Geometry Import

CAPRI will provide geometry import and initial preprocessing for the GPW. CAPRI supports OpenCASCADE. STEP and IGES files can be imported via the OpenCASCADE kernel into CAPRI. Once imported, the CAD model can be fully queried and used by downstream tools. The OpenCASCADE support in CAPRI provides a unique opportunity to import both STEP and IGES file via an open source kernel that is not encumbered by commercial licensing.

Identification and Repair of Geometry not Imported Correctly

The import process involves parsing the geometry in detail and automatically preparing it for watertight tessellation. This process produces diagnostic information about the topology if any failures or errors are encountered. The tessellation from CAPRI provides information on the location of the error on a topological entity or group. For example, a trimming edge loop may contain degeneracies, which prevent watertight tessellation. Errors can be classified into geometric defects in face trimming geometry.

Geometry defects can result in tessellation errors that can prevent creation of a watertight tessellation.

These include:

- Degenerate triangles
- Improperly oriented triangles
- Missing triangles

Softer tessellation errors include poor triangle quality such as high aspect ratio caused by sliver faces, even though the tessellation itself may be watertight.

This objective was de-emphasized in the Phase 1 effort in favor of a more concerted effort on De-featuring/Simplification due to the fact that software infrastructure required for both objectives was more readily prototyped in the context of De-featuring.

De-featuring/Simplification

CADNexus developed a methodology to identify topological groups that represent features such as holes, bosses, etc. that can be isolated based on bounding edge loops and other well defined markers. This task will investigate the possible approaches to automatically identify/detect such groups based user specified parameters such as length scales. Investigate the feasibility of using the feature identification capability to remove selected topology from the BRep.

CADNexus demonstrated automatic feature removal on a test part provided by the technical point of contact. One of the components of the overall assembly contains representative features of interest and we chose it for testing and analysis. Selectable features include through- holes, pockets, and bosses.

The approach taken was found to be efficient, robust, and usable to rapidly create multiple configurations. The feature identification is based on traversing the model and identifying removable features from the primary or base. The approach was demonstrated on a reasonably complex feature consisting of multiple faces and embedded features one inside another.

Automatic Generation of a Unified Watertight Mesh Over One or More Components which Closes Gaps and Holes not selected for Retention

Gap and hole closing of selected features is addressed in De-featuring/Simplification. At the mesh level it is possible to detect and close gaps and other defects in the mesh that prevent watertight tessellation or mesh. Typical defects are listed in the discussion on Identification and Repair of Geometry not Imported Properly section above. In the test model, the mesh could not be made watertight as it contained a self-intersecting tessellation. Problematic triangles are identified and removed.

Implementation and tuning of a constrained version of the Ball-Pivot algorithm that would re- tessellate the face by sampling vertices and edges from the removed triangles is planned for future development. This will form the basis for closing any holes and gaps in the tessellation caused by geometry defects.

Export resulting geometry and/or mesh to most formats commonly used in grid generation tools

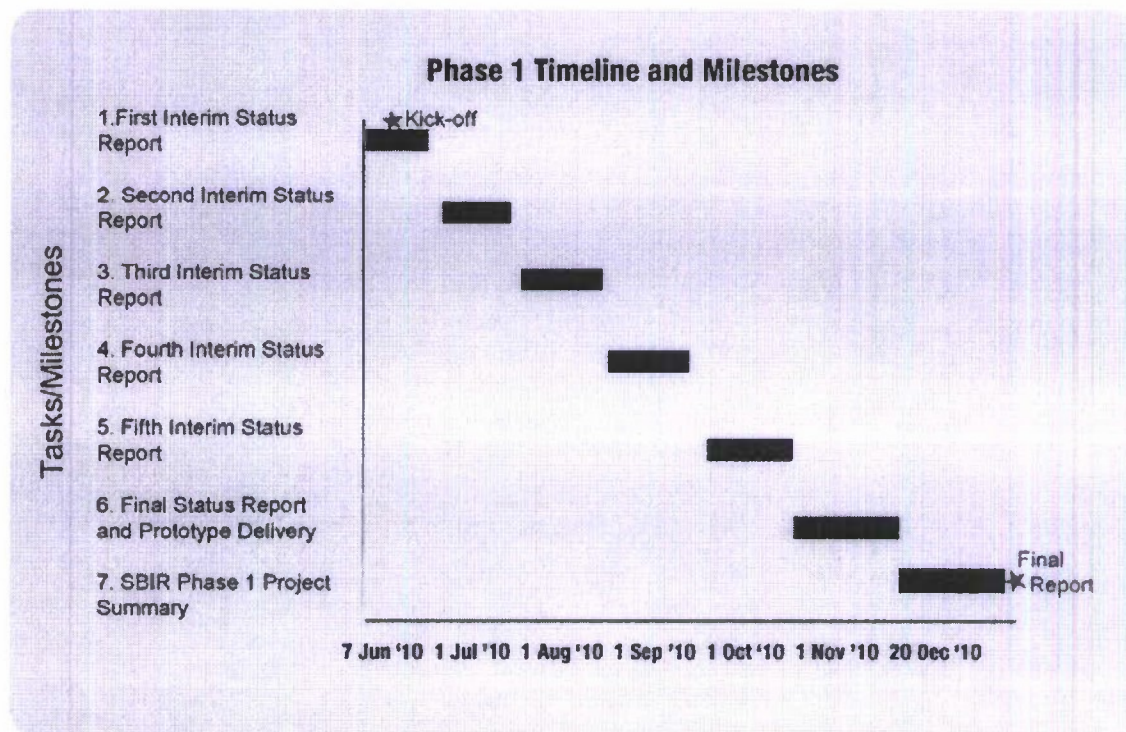
CADNexus demonstrated that the GPW exports the CAD geometry to commonly used grid generation tools such as Chimera Grid Tools, Cart3D, and SolidMesh. Export in STL format is also available and provides a path to most commercial preprocessing tools for further meshing and simulation. More comprehensive coverage will be addressed in the Phase 2 effort.

Comparison with Current Technology

One of the key areas of focus of this effort was to heal a CAD model in as automated a manner as possible realizing that some human intervention or guidance is needed to complete the task. CADNexus has approached this from a very different point of view than current industry applications. One class of such applications heals the geometry BRep whereas others focus entirely on fixing the STL or triangulated representation of the model. Both have several key deficiencies when it comes to automation and preservation of accuracy. CADNexus has emphasized its dual BRep-Tessellation approach as the underlying theme of the geometry processing effort, with the ultimate objective of arriving at a watertight tessellation.

2.2.2.4. Schedule and Milestones

Schedule Graphic



2.2.2.5. Deliverables Description

CADNexus anticipates delivery of the Final Report on Wednesday, December 22, 2010.

CADNexus anticipates delivery of the prototype package also on Wednesday, December 22, 2010. The prototype package will consist of source code for the GPW (including the specialized version of CNExplorer) and runtime libraries for CAPRI support. Instructions and make files will also be provided. OpenCASCADE libraries will also be needed to run the GPW. These can be obtained from the OpenCASCADE web site.

2.2.2.6. Technology Transition and Technology Transfer Targets and Plans

Transfer plans include delivery of the software prototype as described in section 2.2.2.5 above. Delivery will be to the Aerodynamics Technology System Simulation and Development Directorate, Aviation and Missile Research, Development and Engineering Center. CADNexus anticipates that some centers at NASA will be interested in the technology. We anticipate delivery to NASA early in 2010.

ESI Group has expressed interest in the technology as well. We expect to meet with ESI early in 2010 to discuss commercialization of the technology.

2.2.2.7. Quad Chart

Next page.

CADNEXUS

Automated Preparation of Geometry
 Models for Computational Applications

CADNexus, Inc.

Burlington, MA

Proposal No.: A093-132-1055



LeverArm part before
 and after de-featuring
 using the Geometry
 Preprocessing
 Workbench.

User can specify
 features to retain or
 remove

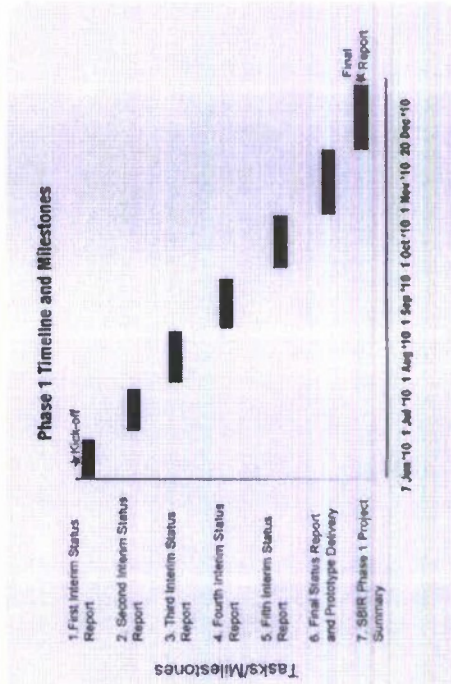
Result can be exported
 in commonly used
 format

New Ideas

- A novel hybrid Brep-Discrete approach for geometry preparation
- *Stylized ball-and-pivot algorithm* for healing geometry that prevents generation of watertight triangulations necessary for high fidelity analysis and outer/inner mold line extraction

Impact

- Drastic reduction in time required to prepare real-world geometry for high fidelity analysis such as Computational Fluid Dynamics
- Target reduction is to reduce what in some cases takes weeks to under a day
- Enables more efficient CFD and other high fidelity analysis with faster turn-around times resulting in improved readiness for our military
- Enables companies designing and building commercial products to get to market more quickly with higher quality products



NON-PROPRIETARY

3. FUNDING REPORT

Not Applicable

4. TECHNICAL REPORT

4.1. Project Progress

4.1.1. Progress Against Planned Objectives

Objective 1: Import of production level CAD files

CADNexus demonstrated the ability to import geometry via neutral STEP files and IGES files. Since GPW uses CAPRI, other file formats such as Parasolid can be enabled with minimal effort. CAPRI uses OpenCASCADE as the underlying kernel to process neutral files. This objective was met according to plan.

Objective 2: Identification and repair of geometry not imported correctly

The import process involves parsing the geometry in detail and automatically preparing it for watertight tessellation. This process produces diagnostic information about the topology if any failures or errors are encountered. The tessellation from CAPRI provides information on the location of the error on a topological entity or group. For example, a trimming edge loop may contain degeneracies, which prevent watertight tessellation. Errors can be classified into geometric defects in face trimming geometry.

- Errors in boundary edge order
- Small/degenerate edges
- Disconnected edges
- Vertices displaced from edge geometry
- Vertices/Edges displaced from face geometry
- Defects in the tessellation
- Self-intersecting faces

Geometry defects can result in tessellation errors that can prevent creation of a watertight tessellation. These include:

- Degenerate triangles
- Improperly oriented triangles

- Missing triangles

Softer tessellation errors include poor triangle quality such as high aspect ratio caused by sliver faces, even though the tessellation itself may be watertight.

Objective 2 was de-emphasized in the Phase 1 effort in favor of a more concerted effort on Objective 3 due to the fact that software infrastructure required for both Objectives 2 and 3 was more readily prototyped in the context of Objective 3. Identification of geometry defects was accomplished according to plan. While advanced techniques for healing were investigated and show promise, they are not built into the current GPW prototype. Additional work in this area is planned contingent on additional funding.

Objective 3: Identification of features and automatic removal of internal / external selected features

CADNexus has demonstrated automatic feature removal on test parts provided by the technical point of contact. One component of the overall assembly contains representative features of interest and we chose it for testing and analysis. A current limitation of the GPW is that it can only process a single body or volume at once. Generalization of the GPW to handle multiple volumes/bodies is slated for later development. Additional development is slated to enable the user to select a feature such as a fin, then click on a "select like" button and have the application select all of the fins satisfying a specified constraint. The user can then de-select as needed. The user will also be given the ability to select geometric features by specifying a global size criterion whereby all features satisfying the size criterion are selected. Selectable features include through-holes, pockets, and bosses.

The approach taken was found to be efficient, robust, and usable to rapidly create multiple configurations. The feature identification is based on traversing the model and identifying removable features from the primary or base features. The approach was demonstrated on a reasonably complex feature consisting of multiple faces and embedded features one inside another. These features span multiple faces, including rivet chamfers, making it non-trivial to automatically remove these features.

Objective 4: Automatic generation of a unified watertight mesh over one or more components which closes gaps and holes not selected for retention

Gap and hole closing of selected features is addressed in Objective 3. At the mesh level it is possible to detect and close gaps and other defects in the mesh that prevent watertight tessellation or mesh. Typical defects are listed in Objective 2.

Implementation and tuning of a constrained version of the Ball-Pivot algorithm that would re-tessellate the face by sampling vertices and edges from the removed triangles is planned for future development. This will form the basis for closing any holes and gaps in the tessellation caused by geometry defects.

Objective 5: Export resulting geometry and/or mesh to most formats commonly used in grid generation tools.

CADNexus demonstrated that the GPW exports the CAD geometry to commonly used grid generation tools such as Chimera Grid Tools and Cart3D and SolidMesh. Export in STL format is also available and provides a path to most commercial preprocessing tools for further meshing and simulation. More comprehensive coverage will be addressed in the Phase 2 effort. We anticipate that the de-featured representation prepared in GPW can be similarly passed to such tools for meshing.

4.1.2. Technical Accomplishments

CADNexus has developed and demonstrated prototype software that nominally meets the requirements set forth in the Phase 1 solicitation and provides proof-of-concept as well as a sound foundation for additional development. The CADNexus prototype is called the Geometry Preparation Workbench (GPW). The GPW lays down the groundwork for building out a fully operational software product that drastically reduces the time and effort required to prepare CAD geometry for CFD and other high fidelity analysis. The Phase 1 effort focused primarily on geometry import, user-driven de-featuring, user interface and supporting infrastructure. Semi-automated repair techniques were investigated but no development or prototyping was done. CADNexus has adopted a novel hybrid BRep-Discrete approach to tackle the challenge of geometry preparation. The objectives and findings of the effort are summarized below. The GPW uses CAPRI as the neutral geometry interface.

4.1.3. Improvements to Prototypes

The GPW prototype was built to function within the CADNexus CNExplorer GUI framework. The feature set of the GPW is detailed in section 4.1.1 above.

4.1.4. Significant Changes to Technical Approach to Date

There was one significant change to the technical approach. Initially CADNexus planned on tackling the healing and inner/outer mold line extraction problems early on in the effort. We determined that this required data structure changes within CAPRI and further, that those data structure changes would be better completed in the context of de-featuring. This led to de-emphasis of geometry healing and a more focused effort aimed at automatic feature identification and de-featuring functionality.

4.1.5. Deliverables for this Period

Interim Report 1 delivered on July 1, 2010.

Interim Report 2 delivered on Aug. 1, 2010.

Interim Report 3 delivered on Sep. 1, 2010.

Interim Report 4 delivered on Oct. 1, 2010.

Interim Report 5 delivered on Nov. 1, 2010.

Final Report delivered approximately Dec. 22, 2010.

Research Summary delivered approximately Dec. 22, 2010.

4.1.6. Technology Transition and Transfer this Period

4.1.6.1. Technology Transition and Transfer Description

CADNexus will transfer the Geometry Preprocessing Workbench (GPW) source code and make files, CNExplorer source code and make files, CAPRI runtime libraries to support the function of the GPW. OpenCASCADE libraries will also be required to run the GPW and should be downloaded from www.opencascade.org. The basic capability provided by the GPW is opening real-world models, identifying features and allowing de-featuring, and exporting to common formats.

4.1.6.2. Technology Transition and Transfer List

The recipient of the technology is the U.S. Army as a final deliverable under this Phase 1 SBIR.

4.1.6.3. Technology Transition and Transfer Contacts

System Simulation and Development Directorate

Aviation and Missile Research, Development and Engineering Center

U.S. Army Research, Development and Engineering Command

4.1.7. Publications this Period

Not Applicable.

4.1.8. Meetings and Presentations this Period

Not Applicable.

4.1.9. Issues or Concerns

No issues or concerns.

4.2. Project Plans

4.2.1. Planned Activities

CADNexus has submitted a Phase 2 proposal but aside from that anticipates transitioning the technology to other government agencies such as NASA as well as commercial entities with close ties to the automotive industry. CADNexus will continue to seek funding for additional research and development. We will also continue to seek out potential users who can benefit from this work.

CADNexus also intends to submit a paper based on the research performed in this effort to one or more conferences for presentation in 2011.

4.2.2. Specific Objectives for Next Period

Not Applicable.